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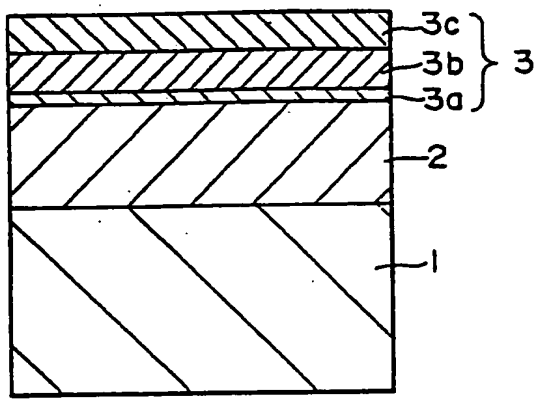
(54) Ohmic electrode and method of forming the same

(57) There are provided an ohmic electrode capable of operating elements stably for a long period by making contact specific resistance smaller and also increasing thermal stability thereof and a method of forming the same. An electrode layer is formed on a p-type compound semiconductor layer composed of p-type GaN and so on through a contact layer composed of p-type GaN and so on. The contact layer is formed by an MBE method, and the hole density is set higher than that of the p-type compound semiconductor layer. The electrode layer is formed by laminating a transition metal layer composed of a transition metal other than gold or platinum, a platinum layer and a gold layer one after another and annealing the laminated layers thereafter. With this, the platinum layer is made to adhere closely to the p- type compound semiconductor layer by the transition metal layer while preventing gold from diffusing toward the p- type compound semiconductor layer with the platinum layer.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an ohmic electrode for a p-type compound semiconductor layer containing at least one type among groups composed of gallium, aluminum, boron and indium as a III group element and nitrogen and a method of forming the ohmic electrode.

Description of the Related Art

Nitride III-V group semiconductors such as GaN, AlGaN, InGaN or BAlGaInN are considered to be promising as the material for forming a luminous element capable of emitting red or ultraviolet rays because of a reason that a band gap Eg can be varied from 1.8 eV to 6.2 eV. Further, attention is being paid also as a material for forming a Field Effect Transistor (FET) as an environment-proof element utilizing the property of a wide-gap semiconductor.

In these elements, the technique related to an ohmic electrode becomes very important in point of securing stabilized operation. For example, an ohmic electrode formed by laminating Ni and Au has been heretofore used as an ohmic electrode for a p-type GaN layer (Japanese Patent Laid-Open No. Hei 6-275868).

In a conventional ohmic electrode, however, the value of contact specific resistance is approximately $1x10^{-2}$ Ω cm^2, and has been fairly large as compared with the value of contact specific resistance in an ohmic electrode of another general semiconductor element (for example, approximately $1x10^{-5}$ Ω cm^2 in an ohmic electrode for a p-type GaAs layer). In addition, the conventional ohmic electrode had such a specific character that the value of contact specific resistance becomes larger when annealing is performed at a temperature of 400°C or higher. As a result, there has been such a problem that the value of contact specific resistance becomes large due to Joule heat generated at a contact portion between a semiconductor layer and a metal layer at the drive time of these elements or rise of ambient temperature and element characteristics are deteriorated.

OBJECT AND SUMMARY OF THE INVENTION

It is conceivable that the value of the contact specific resistance in the ohmic electrode for a p-type GaN layer is larger as compared with a value of contact specific resistance in an ohmic electrode of another general semiconductor element as described above because of such a reason that a large barrier against holes is produced on the interface between the semiconductor layer and the metal layer since an energy difference $E_V - \phi_V$ (7.8 eV at RT) between the summit of a valence band and vacuum level of GaN is larger as compared with a work function ϕ of a metal forming an electrode (for example, 5.2 eV for gold).

Further, it is conceivable that it is one of the causes for a value of contact specific resistance becoming larger by annealing at a high temperature in a conventional ohmic electrode that gold is diffused into a GaN layer by means of annealing.

The present invention has been made in view of such problems, and has for its object to provide an ohmic electrode in which the element can be made to operate stably for a long period by reducing the contact specific resistance and also increasing thermal stability thereof, and a method of forming the same.

An ohmic electrode according to the present invention is used for a p-type compound semiconductor layer containing at least one type among groups composed of gallium, aluminum, boron and indium as a III group element and nitrogen, and is provided with an electrode layer composed of a complex containing at least one type among gold, platinum and a transition metal element other than gold or platinum.

A method of forming an ohmic electrode according to the present invention is for forming an ohmic electrode for a p-type compound semiconductor layer containing at least one type among groups composed of gallium, aluminum, boron and indium as a III group element and nitrogen, and comprises a process of forming a transition metal layer containing at least one type among transition metal elements other than gold or platinum on a p-type compound semiconductor layer, forming thereon a platinum layer composed of platinum, and further forming thereon a gold layer composed of gold, and a process of annealing after forming the transition metal layer, the platinum layer and the gold layer, respectively.

In this ohmic electrode, wirings are connected to a p-type compound semiconductor layer through the electrode layer. When voltage is applied to the p-type compound semiconductor layer through these wirings and the electrode layer, holes are injected into the p-type compound semiconductor layer from the electrode layer. Here, since the electrode layer is formed of a complex containing at least one type among gold, platinum and a transition metal element other than gold or platinum between the electrode layer and the p-type compound semiconductor layer, the barrier against the holes becomes smaller and the value of the contact specific resistance becomes small.

According to this method of forming an ohmic electrode, annealing is performed after forming a transition metal layer, a platinum layer and a gold layer one after another on a p-type compound semiconductor layer. In some cases, a reaction occurs in a part among the transition metal layer, the platinum layer and the gold layer by the annealing, and these layers become a transition metal containing layer, a platinum containing layer and a gold containing layer. At this time, the platinum contain-

ing layer prevents gold from diffusing toward the p-type compound semiconductor layer, and the transition metal containing layer also makes the platinum containing layer adhere closely to the p-type compound semiconductor layer.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a composition diagram showing an ohmic electrode according to an embodiment of the present invention;

Fig. 2 is a plan view of a specimen produced in a first embodiment of the present invention seen from an electrode layer side;

Fig. 3 is a sectional diagram taken along a line A-A showing the structure of the specimen shown in Fig. 2;

Fig. 4 is a characteristic diagram showing the relationship between a resistance value between electrodes and an annealing temperature in the embodiment of the present invention;

Fig. 5 is a relational diagram between a resistance value between electrodes and a distance between electrodes in the specimen shown in Fig. 2; and Fig. 6 is a composition diagram showing a specimen produced in a fifth embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will be explained in detail hereinafter with reference to the drawings.

Fig. 1 shows a structure of an ohmic electrode according to one embodiment of the present invention. This ohmic electrode is for making ohmic contact with a p-type compound semiconductor layer 1 (such as a p-type GaN layer) containing at least one type among groups composed of gallium (Ga) , aluminum (Al) , boron (B) and indium (In) as III group elements and nitrogen (N). Besides, this p-type compound semiconductor layer 1 is formed on a substrate not shown by a Metal Organic Chemical Vapor Deposition (MOCVD) method.

This ohmic electrode is structured of a contact layer 2 formed on the p-type compound semiconductor layer 1 and an electrode layer 3 formed on this contact layer 2.

The contact layer 2 is formed of a p-type compound semiconductor which has been grown by an MBE method using hydrogen gas (H_2) at time of growth. This p- type compound semiconductor contains at least one type among groups composed of gallium, aluminum, boron and indium as III group elements, and has the same structure elements as the p-type compound semiconductor layer 1. For example, when the p-type compound semiconductor layer 1 is formed of GaN added with magnesium (Mg) as p-type impurities, the contact layer 2 is also formed of GaN added with magnesium as p-type impurities.

However, since the contact layer 2 is formed by an MBE method using no hydrogen gas at the time of growth, the contact layer 2 does not contain hydrogen (H). The contact layer 2 is different in this point from that the p-type compound semiconductor layer 1 formed by an MOCVD method generally using hydrogen gas as carrier gas contains hydrogen. Since acceptors are compensated when hydrogen is introduced in p-type nitride III-V group semiconductors, when the semiconductor is formed by the MOCVD method, the resistance value is large immediately after formation, thus requiring to perform carrier activation processing such as electron beam radiation and thermal annealing (see H. Amano et al., Jpn. J. Appl. Phys. 28(1989) 12112., S. Nakamura et al., Jpn. J. Appl. Phys. 31(1992) 1139 for carrier activation processing). Therefore, the p-type compound semiconductor layer 1 shows hole density of approximately $1x10^{17}$ to $1x10^{18}$ cm^{-3} for the first time by performing such carrier activation processing.

On the other hand, since hydrogen gas is not used in general in the MBE method, it is not required to perform carrier activation processing when the compound semiconductor layer is formed by the MBE method, but a value of approximately $1x10^{19}$ cm^{-3} which is higher than that when formed by the MOCVD method is also obtainable for the hole density (see M.S. Brandt et al., Aool. Phys. Lett. 64 (1994) 2264). The contact layer 2 in the present embodiment also has hole density of approximately $1x10^{19}$ cm^{-3} which is higher as compared with that of the p-type compound semiconductor layer 1.

As described above, in the present embodiment, the contact specific resistance is made smaller by providing the contact layer 2 having hole density higher than that of the p-type compound semiconductor layer 1 between the p-type compound semiconductor layer 1 and the electrode layer 3. Namely, since the current flowing in the p-type compound semiconductor layer 1 from the electrode layer 3 is principally a tunnel current, by connecting the p-type compound semiconductor layer 1 with the electrode layer 3 through the contact layer 2 having high hole density, the barrier between the p-type compound semiconductor layer 1 and the electrode layer 3 is made smaller so as to make it easier to apply a tunnel current.

The electrode layer 3 is formed of a complex containing at least one type among gold, platinum (Pt) and a transition metal other than gold or platinum. As the complex, for example, that which has a structure in which a transition metal layer 3a containing at least one type of transition metal elements other than gold or plat-

inum, a platinum layer 3b composed of platinum and a gold layer 3c composed of gold are laminated one after another from the side of the p-type compound semiconductor layer 1 or that which is annealed after these transition metal layer 3a, platinum layer 3b and gold layer 3c are laminated one after another is preferable.

Besides, it is conceived for the transition metal layer 3a, the platinum layer 3b and the gold layer 3c that a part of these respective layers reacts by applying annealing. Therefore, explanation is made herein assuming that respective layers after annealing are, although not shown, a transition metal containing layer containing at least one type of transition metal elements other than gold or platinum, a platinum containing layer containing platinum and a gold containing layer containing gold. Presumably, since these transition metal containing layer, platinum containing layer and gold containing layer have reacted to each other sometimes, it is not possible to separate them explicitly.

The transition metal layer 3a is formed of, for example, nickel, palladium (Pd) , cobalt (Co), titanium (Ti) or molybdenum (Mo) . Similarly, the transition metal containing layer contains, for example, nickel, palladium, cobalt, titanium or molybdenum. In the transition metal layer 3a or the transition metal containing layer, the contact layer 2 and the platinum layer 3b or the platinum containing layer are made to adhere very closely to each other so as to make the barrier against holes existing among them smaller utilizing such a specific character that the transition element such as nickel reacts to nitrogen easily thereby to form an interstitial nitride. Therefore, the thickness of the transition metal layer 3a is as thin as approximately 10 nm for instance as compared with the platinum layer 3b and the gold layer 3c.

Further, when nickel or palladium is used for the transition metal layer 3a or the transition metal containing layer, it is possible to make discontinuity of the contact layer 2 with the valence band smaller because the work function * of nickel or palladium is because the work function ϕ of nickel or palladium is comparatively large, which is preferable. Furthermore, since palladium has a property of adsorbing hydrogen, it is possible to adsorb hydrogen on the surface of the p-type compound semiconductor layer 1 so as to increase the hole density on the surface when the p-type compound semiconductor layer 1 and the electrode layer 3 are brought into direct contact with each other without through the contact layer 2, which is preferable.

The platinum layer 3b or the platinum containing layer is for preventing gold from diffusing into the contact layer 2 by the rise of temperature utilizing the fact that platinum is a high melting-point metal. Further, since platinum has the largest work function ϕ (5.7 eV which is larger than the work function 5.2 eV of gold) among metals having high conductivity, discontinuity with the valence band of the contact layer 2 (viz., a p-type compound semiconductor) is checked to the minimum. Besides, the thickness of the platinum layer 3b is approximately 100 nm for instance.

The gold layer 3c or the gold containing layer is for connecting wirings not shown composed of gold for instance to the electrode layer 3 by bonding. Besides, the thickness of the gold layer 3c is approximately 200 nm for instance.

An ohmic electrode having such a structure can be formed as described hereunder.

First, on the p-type compound semiconductor layer 1 formed by the MOCVD method and applied with appropriate carrier activation processing, a p-type compound semiconductor having the same structural elements as the p-type compound semiconductor layer 1 is grown by the MBE method. Besides, the growth by the MBE method is made without using hydrogen gas. With this, the contact layer 2 is formed.

Then, a transition metal layer 3a is formed on the contact layer 2 by vacuum-depositing a transition metal other than gold or platinum in the depth of 10 nm for instance. Thereafter, a platinum layer 3b is formed on the transition metal layer 3a by vacuum-depositing platinum in the thickness of 100 nm for instance. Furthermore, a gold layer 3c is formed on the platinum layer 3b by vacuum-depositing gold in the thickness of 200 nm for instance. With this, an electrode layer 3 in which the transition metal layer 3a, the platinum layer 3b and the gold layer 3c are laminated one after another is formed.

Further, annealing may be applied further after forming these respective layers. With this, respective layers of the transition metal layer 3a, the platinum layer 3b and the gold layer 3c become a transition metal containing layer, a platinum containing layer and a gold containing layer in which a part of the above-mentioned respective layers have reacted.

An ohmic electrode thus formed functions as described hereunder.

In the ohmic electrode, wirings are connected to the p-type compound semiconductor layer 1 through the contact layer 2 and the electrode layer 3. When predetermined voltage is applied to the p-type compound semiconductor layer 1 through the wirings and the electrode layer 3, holes are injected into the p-type compound semiconductor layer 1 from the electrode layer 3 through the contact layer 2. Namely, the current flows from the electrode layer 3 to the p-type compound semiconductor layer 1.

Here, since the contact layer 2 has hole density higher than that of the p-type compound semiconductor layer 1 at the interface between the contact layer 2 and the electrode layer 3, a tunnel current is liable to flow therethrough. Further, since the contact layer 2 and the platinum layer 3b or the platinum containing layer are made to adhere very closely to each other by means of the transition metal layer 3a or the transition metal containing layer of the electrode layer 3, the barrier against holes has been made smaller. Furthermore, since the platinum layer 3b or the platinum containing layer is connected to the contact layer 2 through the thin transition

metal layer 3a or the transition metal containing layer, discontinuity of the contact layer 2 with the valence band has been made smaller. Namely, the contact specific resistance has been made smaller.

In addition, since the platinum layer 3b or the platinum containing layer is inserted between the gold layer 3c or the gold containing layer and the contact layer 2, the gold is prevented from diffusing toward the contact layer 2 even when Joule heat is generated by application of voltage, thus increasing the temperature or rising the ambient temperature. Thus, even when the temperature rises, it is controlled that the contact specific resistance becomes higher.

As described above, according to an ohmic electrode related to the present embodiment, the contact layer 2, the transition metal layer 3a or the transition metal containing layer and the platinum layer 3b or the platinum containing layer are provided consecutively from the side of the p-type compound semiconductor layer 1. Therefore, it is possible to make the value of the contact specific resistance smaller. Further, the transition metal layer 3a or the transition metal containing layer and the platinum layer 3b or the platinum containing layer are provided one after another from the side of the p-type compound semiconductor layer 1. Thus, it is possible to increase thermal stability. Accordingly, it is possible to have the element operate stably for a long period.

Further, according to a method of forming an ohmic electrode related to the present embodiment, since annealing is performed after laminating the transition metal containing layer 3a, the platinum layer 3b and the gold layer 3c one after another, it is possible to have the platinum layer 3b adhere closely to the p-type compound semiconductor layer 1 by means of the transition metal layer 3a while preventing gold from diffusing toward the p-type compound semiconductor layer 1 by the platinum layer 3b. Thus, it is possible to realize an ohmic electrode according to the present embodiment.

Furthermore, the effects of the present invention will be described with reference to concrete embodiments.

(The First Embodiment)

Fig. 2 shows a structure, seen from the side of an electrode layer 13, of a specimen produced in a first embodiment. Fig. 3 shows a sectional structure along a line A-A of the specimen shown in Fig. 2. Besides, the portion of the electrode layer 13 is shown with slashes in Fig. 2 for distinguishing between the electrode layer 13 and the p-type compound semiconductor layer 11.

In the present embodiment, first that in which a p-type compound semiconductor layer 11 is formed on an appropriate sapphire substrate 10 has been prepared. Besides, this p-type compound semiconductor layer 11 is formed by growing GaN added with magnesium as p-type impurities by the MOCVD growth, and carrier activation is performed by annealing at 800°C and for 10 minutes in a nitrogen gas atmosphere after growth is made. The hole density of the p-type compound semiconductor layer 11 is $4x10^{17}$ cm^{-3}, and the thickness thereof is approximately 2 μm.

Then, prior to forming the electrode layer 13, a photoresist film not shown has been applied onto the p-type compound semiconductor layer 11, and a pattern corresponding to the configuration of the electrode layer 13 shown in Fig. 3 has been formed by means of photolithography. This pattern is for forming a plurality of second electrodes 14 having different distances between electrodes for a first electrode 14a by removing a part of the electrode layer 13 to show a ring shape. Thereafter, the surface oxide film of the p-type compound semiconductor is removed with a mixed liquid of ammonium fluoride and hydrofluoric acid (HF), and cleaning has been performed thereafter with pure water.

Then, the p-type compound semiconductor is inserted into a deposition machine, and the electrode layer 13 in which the transition metal layer 13a, the platinum layer 13b and the gold layer 13c are laminated has been formed by depositing nickel in 10 nm, platinum in 100 nm and gold in 200 nm in succession in a vacuum of approximately $1x10^{-4}$ Pa. Thereafter, a photoresist film not shown is removed together with the transition metal layer 13a, the platinum layer 13b and the gold layer 13c formed thereon, and, as shown in Fig. 2 and Fig. 3, a specimen in which a first electrode 14a and a plurality of second electrodes 14b having distances among electrodes at 4 μm to 36 μm are formed has been produced.

After the specimen is produced as described above, resistance values among respective electrodes have been measured, respectively. Thereafter, the specimen was annealed in a nitrogen gas atmosphere, and variations of resistance values among respective electrodes have been measured, respectively. The measurement was made at the annealing temperature of 200°C , 300°C , 400°C , 500°C , 600°C , 700°C and 800°C, respectively. The annealing period of time was set at 30 seconds, respectively.

The results on those that have the distance among electrodes at 24 μm are shown in Fig. 4 while comparing with a conventional example. Besides, the conventional example means an example in which the platinum layer 13b in the present embodiment has been removed and Ni has been used as the transition metal layer 13a. Further, that in which only a cobalt layer has been formed on the p-type compound semiconductor layer 11 is also shown in Fig. 4 as a reference example.

Presumably, the resistance value here is obtained by adding the contact resistance value and the resistance value of the p-type compound semiconductor layer 11 to each other. However, since annealing is performed at the annealing temperature (800°C) in the case of carrier activation in the p-type compound semiconductor layer 11 or lower, it is conceived that the var-

iation quantity of the resistance value of the p-type compound semiconductor layer 11 is small. Further, the change of the surface of the p-type compound semiconductor layer 11 caused by diffusion of a metal is considered as the change of the contact resistance value. Therefore, the change of the resistance value shown in Fig. 4 can be regarded in the same light with the change of the contact specific resistance.

As it is understood from Fig. 4, the resistance value before annealing was the smallest in the conventional example. Namely, it is conceivable that the contact specific resistance becomes larger by annealing in the conventional example. As against this, in the present embodiment, although the resistance value becomes larger temporarily by applying annealing, the resistance value has become the smallest by annealing at 700°C. Furthermore, the resistance value has become larger again when annealing is applied at 800°C . Further, when the resistance value before annealing in the conventional example and the resistance value before annealing in the present embodiment are compared with each other, it has been found that the resistance value in the present embodiment is smaller, and, when the smallest resistance value in the conventional example (before annealed) and the smallest resistance value in the present embodiment (annealed at 700°C) are compared with each other, it has also been found that the smallest resistance value in the present embodiment is smaller.

Further, when the value of the contact specific resistance when annealing is performed at 700°C was estimated, the value showed a comparatively small value at $3.2 \times 10^{-2}\ \Omega\,cm^2$ as shown in Fig. 5. Besides, as to the way of estimating the contact specific resistance, the method shown in "G. S. Marlow et al., Solid State Electronics 25(1982) 91" was used. Presumably, the sheet resistance value of the p-type compound semiconductor layer 11 at this time was 14,900 Ω / □.

Therefore, according to the present embodiment, it has been found that the value of the contact specific resistance can be made smaller by the electrode layer 13 in which the transition metal layer 13a composed of nickel, the platinum layer 13b and the gold layer 13c are laminated one after another. In particular, it has been found that thermal stability can also be increased when annealing is performed at 700°C.

(The Second Embodiment)

In a second embodiment, a specimen was produced similarly to the first embodiment except that the transition metal layer 13a of the first embodiment was formed of palladium. Thereafter, the change of the resistance value caused by annealing was examined similarly to the first embodiment. Besides, in order to compare with the first embodiment, that which was cut out of the same wafer as th first embodiment was used for a p-type compound semiconductor layer 11 formed on a sapphire substrate 10.

The results obtained on those that has the distance among electrodes at 24 μm are shown in Fig. 4 similarly to the first embodiment. As it is comprehended from Fig. 4, in the present embodiment, the resistance value becomes smaller by annealing at 800°C, but the resistance value before annealing is performed has been the smallest. Further, when the resistance value before annealing is performed in a conventional example and the resistance value before annealing is performed in the present embodiment are compared with each other, it was found that the resistance value in the present embodiment was smaller.

Therefore, it has been realized that it is possible to make the value of the contact specific resistance smaller by means of an electrode layer 13 in which a transition metal layer 13a composed of palladium, a platinum layer 13b and a gold layer 13c are laminated one after another.

(The Third Embodiment)

In a third embodiment, a specimen was produced in a similar manner as the first embodiment except that the transition metal layer 13a of the first embodiment was formed of cobalt. Thereafter, the change of resistance value caused by annealing was examined similarly to the first embodiment. Besides, in order to compare with the first embodiment, that which has been cut out of the same wafer as the first embodiment was used for a p-type compound semiconductor layer formed on a sapphire substrate 10.

The results on those that have the distance among electrodes at 24 μm are shown in Fig. 4 similarly to the first embodiment. As it is realized from Fig. 4, although the resistance value before annealing was comparatively large, the resistance value becomes the smallest by means of annealing at 700°C in the present embodiment. Further, when the smallest resistance value (before annealing is applied) in the conventional example and the smallest value (annealed at 700°C) in the present embodiment were compared with each other, it was found that the resistance value in the present embodiment was smaller.

Thus, it has been comprehended that, according to the present embodiment, it is possible to make the value of the contact specific resistance smaller and also to increase the thermal stability by annealing at 700°C an electrode layer 13 in which the transition metal layer 13a composed of cobalt, the platinum layer 13b and the gold layer 13c are laminated one after another.

(The Fourth Embodiment)

In a fourth embodiment, a specimen was produced in a similar manner as the first embodiment except that the transition metal layer 13a of the first embodiment was formed of titanium. Thereafter, the change of the

resistance value caused by annealing was examined similarly to the first embodiment. Besides, in order to compare with the first embodiment, that which was cut out of the same wafer as the first embodiment was used for a p-type compound semiconductor layer 11 formed on a sapphire substrate 10.

The results on those that have the distance among electrodes at 24 μm are shown in Fig. 4 similarly to the first embodiment. As it is realized from Fig. 4, although the resistance value before annealing is applied has been comparatively large, the resistance value became the smallest by means of annealing at 800°C in the present embodiment. Further, when the smallest resistance value (before annealing is applied) in the conventional example and the smallest resistance value (annealed at 800°C) in the present embodiment were compared with each other, it was found that the resistance value in the present embodiment was smaller.

Thus, it has been comprehended that, according to the present embodiment, it is possible to make the value of the contact specific resistance smaller and also to increase the thermal stability by annealing at 800°C an electrode layer 13 in which a transition metal layer 13a composed of titanium, a platinum layer 13b and a gold layer 13c are laminated one after another.

(The Fifth Embodiment)

Fig. 6 shows a structure of a specimen produced in a fifth embodiment. In the present embodiment, a p-type compound semiconductor layer 21 formed on a sapphire substrate 20 was prepared first in a similar manner as the first embodiment. Then, an oxide film formed on the surface thereof was removed with a mixed liquid of ammonium fluoride and hydrofluoric acid, and, the p-type compound semiconductor layer 21 on the substrate 20 was inserted into a growth chamber of an MBE growth apparatus after cleaning with pure water and drying.

Thereafter, the substrate temperature was risen up to 850°C and the surface thereof was nitrided by nitrogen plasma, and a gallium beam, nitrogen plasma and a magnesium beam are radiated thereafter so as to grow GaN, thus forming a contact layer 22. At this time, nitrogen was excited by an Electron Cyclotron Resonance (ECR) cell or a Radio Frequency (RF) cell. Further, the cell temperature of gallium was set to 900°C, and the cell temperature of magnesium was set to 200°C to 500°C.

After forming the contact layer 22 in such a manner as described, a transition metal layer 23a composed of nickel, a platinum layer 23b and a gold layer 23c were laminated one after another in the similar manner as the first embodiment, thereby to form an electrode layer 23.

When the contact specific resistance was measured on the specimen produced as described above, it was found that the contact specific resistance was 10^{-3} Ω cm^2 or lower. Namely, it has been found that the value of the contact specific resistance could be made smaller by inserting the contact layer 22 between the p-type compound semiconductor layer 21 and the electrode layer 23.

The present invention has been described above citing embodiments. However, the present invention is not limited to these embodiments, but may be modified in various ways within isometric range thereof. For example, in the above-mentioned embodiment, the contact layer 2 was inserted between the p-type compound semiconductor layer 1 and the electrode layer 3, but it is not necessarily required to insert the contact layer 2 as seen from the first to the fourth embodiments.

Further, the transition metal layers 13a and 23a were formed of a simple substance such as nickel and palladium in the above-mentioned respective embodiments, but may be formed of an alloy with other metals.

As described above, according to an ohmic electrode related to the present invention, an electrode layer composed of a complex containing gold, platinum and at least one type among transition metal elements other than gold or platinum is provided. Therefore, it is possible to make the value of the contact specific resistance smaller and also to increase the thermal stability. Hence, such an effect that the elements can be operated stably for a long period is produced.

Further, according to a method of forming an ohmic electrode related to the present invention, since there are provided a process of forming a transition metal layer, a platinum layer and a gold layer one after another on a p-type compound semiconductor layer and a process of annealing thereafter, it is possible to have the platinum layer adhere closely to the p-type compound semiconductor layer by the transition metal layer while preventing gold from diffusing toward the p-type compound semiconductor layer by means of the platinum layer. Thus, it is possible to realize an ohmic electrode according to the present invention.

Claims

1. An ohmic electrode structure, comprising:

   a p-type compound semiconductor layer containing at least one type among groups composed of Ga, Al, B and In and N; and

   an electrode layer containing at least one type among Au, Pt and transition metal elements excluding Au and Pt on said p-type compound semiconductor layer.

2. An ohmic electrode structure according to Claim 1, wherein said electrode layer is composed of a first layer containing at least one type among transition metal elements excluding Au and Pt, a second layer containing Pt and a third layer containing Au consecutively on said p-type compound semiconductor

layer.

3. An ohmic electrode structure according to Claim 1, wherein said electrode layer is formed of a transition metal layer containing at least one type among transition metal elements excluding Au and Pt, a Pt layer and an Au layer consecutively on said p-type compound semiconductor layer.

4. An ohmic electrode structure according to Claim 1, wherein said electrode layer contains Au, Pt and Pd.

5. An ohmic electrode structure according to Claim 1, wherein said electrode layer contains Au, Pt and Ni.

6. An ohmic electrode structure according to Claim 1, wherein there is provided a contact layer composed of a p-type compound semiconductor containing at least one type among groups of Ga, Al, B and In and N between said p-type compound semiconductor layer and said electrode layer, and the hole density of said contact layer is higher than that of said p-type compound semiconductor layer.

7. A method of forming an ohmic electrode structure, comprising the steps of:

forming a first layer containing at least one type among transition metals excluding Au and Pt on a p- type compound semiconductor layer containing at least one type among groups composed of Ga, Al, B and In and N;

forming a second layer containing Pt on said first layer;

forming a third layer containing Au on said second layer; and

applying heat treatment to said first, second and third layers.

8. A method of forming an ohmic electrode according to Claim 7, wherein said first layer contains Pd.

9. A method of forming an ohmic electrode according to Claim 7, wherein said first layer contains Ni.

10. A method of forming an ohmic electrode according to Claim 7, wherein said first layer is composed of Pd, said second layer is composed of Pt and said third layer is composed of Au.

11. A method of forming an ohmic electrode according to Claim 7, wherein said first layer is composed of Ni, said second layer is composed of Pt, and said third layer is composed of Au.

12. A method of forming an ohmic electrode according to Claim 7, wherein said first layer contains Ni, and the temperature of said heat treatment is set to 600°C to 800°C.

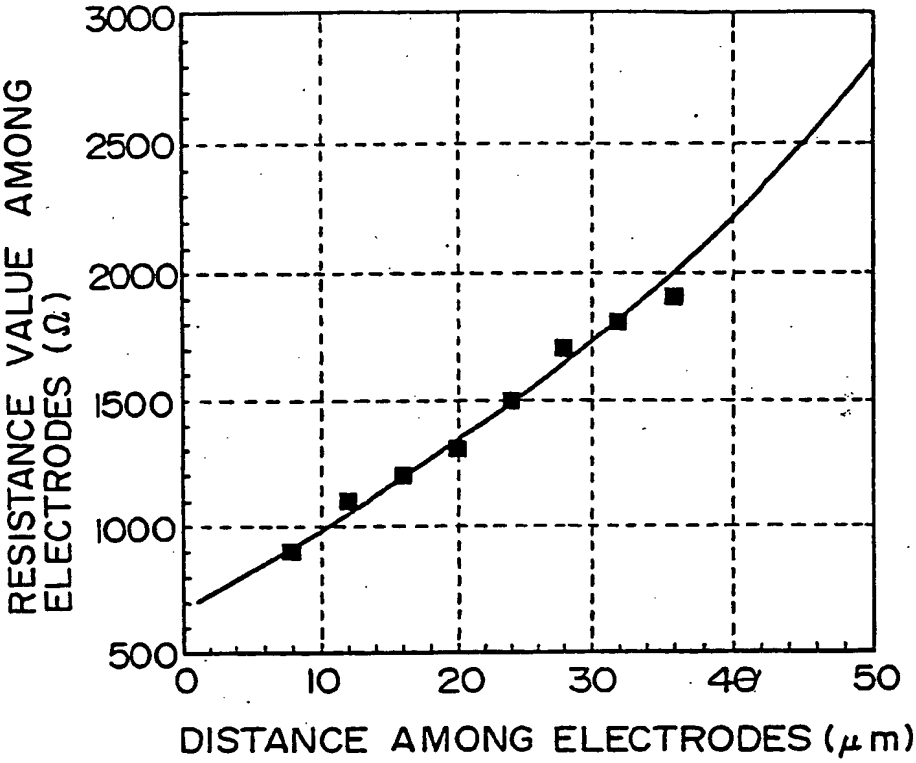
13. A method of forming an ohmic electrode according to Claim 7, further comprising a process of forming a contact layer composed of a p-type compound semiconductor containing at least one type among groups composed of Ga, Al, B and In and N on said p-type compound semiconductor layer by means of molecular beam epitaxy prior to the process of forming said first layer.

14. A semiconductor element having an ohmic electrode structure, wherein said ohmic electrode structure comprises:

a p-type compound semiconductor layer containing at least one type among groups composed of Ga, Al, B and In and N; and

an electrode layer containing at least one type among Au, Pt and transition metal elements excluding Au and Pt on said p-type compound semiconductor layer.

FIG. 5



—— CURVE BY METHOD OF LEAST SQUARES
($\rho c = 3.2 \times 10^{-2} \Omega - cm^2$, Rs = 14900 ohm / □)

■ MEASURED VALUE

FIG. 6

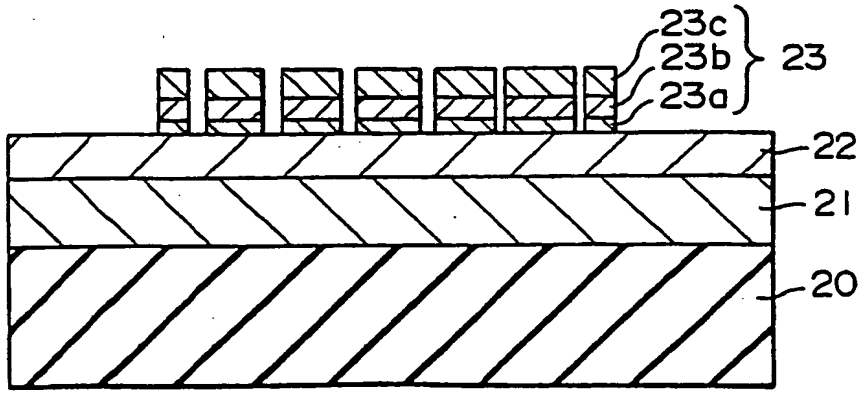
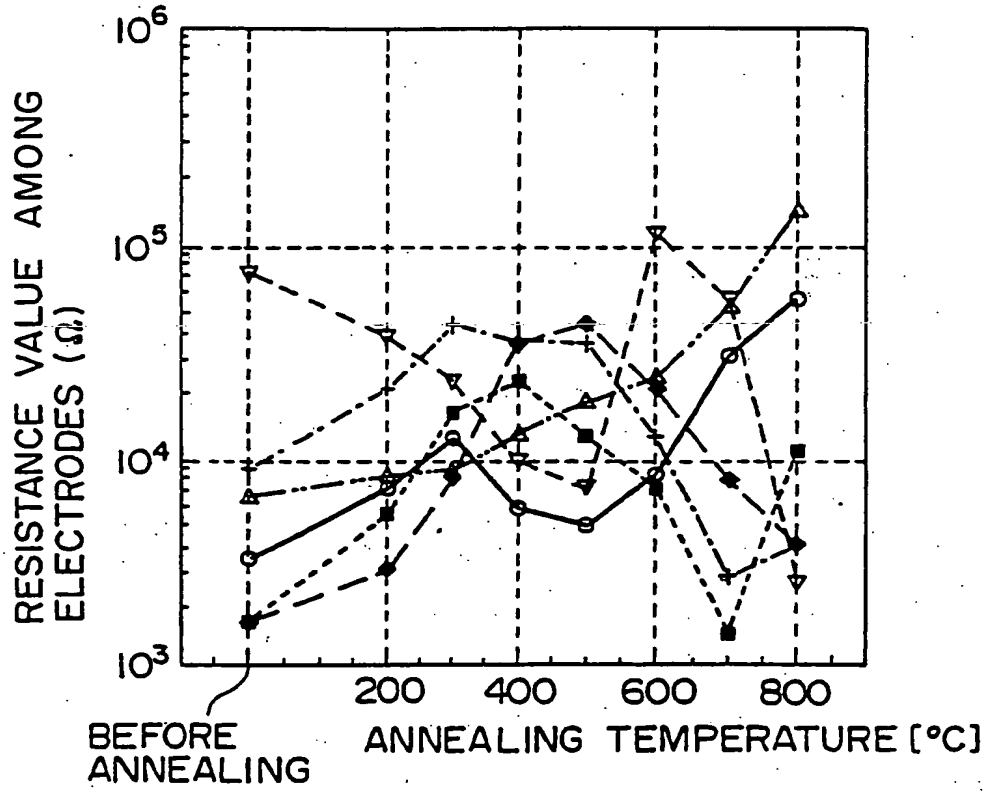


FIG. 4



DISTANCE AMONG ELECTRODES 24μm

—o— CONVENTIONAL EXAMPLE (Ni/Au)

--■-- THE 1ST EMBODIMENT (Ni/Pt/Au)

-◆- THE 2ND EMBODIMENT (Pd/Pt/Au)

—+— THE 3RD EMBODIMENT (Co/Pt/Au)

-▽- THE 4TH EMBODIMENT (Ti/Pt/Au)

--△-- REFERENCE EXAMPLE (Co)

FIG. 1

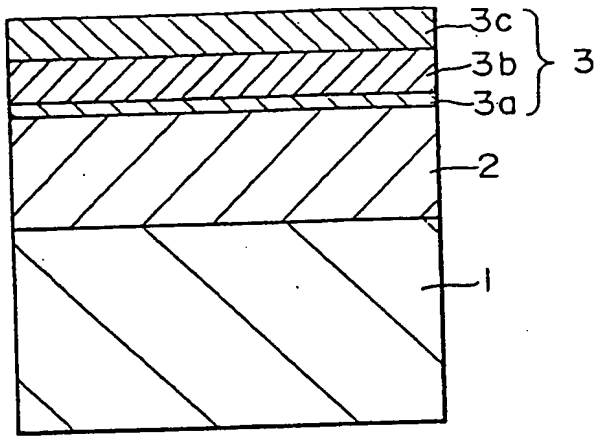


FIG. 2

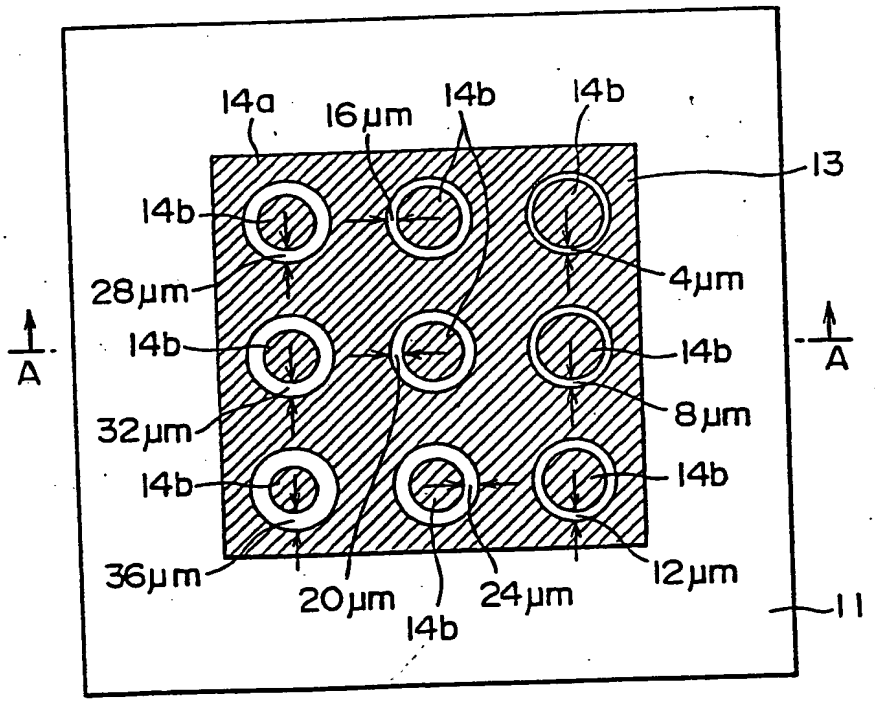


FIG. 3